Sedimentology of the distal fan and lake deposits of the Tianshui-Qinan Basin (Central China): evidences against a possible eolian origin

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ABSTRACT

In this paper we analyze two sections within the Tianshui-Qinan Basin, a closed basin in Central China. The deposits are Miocene and Pliocene in age and in recent times they have been considered as loess. The preliminary sedimentological study indicates a closed lacustrine basin, with a very flat topography in the inner parts. Periodical desiccation and subaerial exposure periods of both mudflats and shallow lakes caused important reworking of the sediments. The lake margins were ramp-like with different energy levels. Low energy lake margins are represented by marls, intraclastic and palustrine limestones, whereas higher energetic levels are indicated by rippled sands and silts.

Key words: *Tertiary, Central China, Tianshui-Qinan Basin, alluvial fan, lake deposits, calcretes.*

INTRODUCTION

The Tianshui-Qinan Basin, is a closed basin in Central China (Fig. 1) that contains a thick sequence of Miocene and some Pliocene deposits, some of them interpreted as loess (Guo *et al.*, 2002). This interpretation is based mostly on the grain size as well as many geochemical indicators (Guo *et al.*, 2002; Liu *et al.*, 2006). However, till now no detailed sedimentological study was carried on these deposits. The aim of this paper is to analyze the deposits of two main sections (Yaodian and top part of QA-I section) of the Qinan Basin. In doing so, we will discuss from the sedimentological point of view, the origin of these deposits, focusing mostly of the "loess problem".

GEOLOGICAL SETTING

The reported sections are located within the Tianshui-Qinan Basin, which is one of the sub-basins of the broad Longzhong Basin, delineated by northeastern Tibetan Plateau, western Qinling Mt., and Qilian Shan-Liupan Shan. Geologically, the Tianshui-Qinan Basin is bounded to the northeast by the Haiyuan fault, to the south by the north Qinling fault, to the north by the Huajia Ling highland and to the west akin to the Linxia Basin. The Neogene strata demonstrate asymmetric facies distribution within the Tianshui-Qinan basin; they are thick and coarse at south, thinner and finer basinward. Close to the piedmont depression along Qinling Mt., seen at Ganquan, the Neogene deposits are up to 1400 m thick, the lower 1000 m mainly consists of alluvial fan and braided fluvial red conglomerates, sandstone and overbank siltstone shed from Qinling, and the topmost 400 m consists of typical lacustrine grey-greenish mudstones and marls. Infill of the central sector of the basin is about 300-500 m thick, mainly consists of fluvial and lacustrine deposits. Further northward, close to Huajia Ling, the sequences are thinner than 300 m, and have recently been dated to 22 Ma old, and interpreted to be eolian deposits to indicate Asian interior desertification in response to uplift of southern Tibet (Guo *et al.*, 2002). This work has put the continental eolian record 14 Ma ahead of previous studies on the Loess Plateau, east of Liupan Shan, where the Red Clay were widely dated to be only 8 Ma (An *et al.*, 2001; Sun *et al.*, 1998). However, the present Liupan Shan, an important longitudinal topographic barrier in north China nowadays, did not exist prior to 8 Ma (Song *et al.*, 2001; Zheng, *et al.*, 2005).

SEDIMENTOLOGY

The study presented here is mostly based on two sections (Yaodian and upper part of QA-I section; Fig. 2), although their correlation and the selection of the intervals studied here is based on overall study of a wide area of the basin (Li *et al.*, in press). The mean thickness of the sections is about 250 m; our study is based on the upper most 100 m of the Miocene infill of the Qinan Basin. Yaodian correlates with the upper part of QA-I section, which has been deeply analyzed by Gou and co-authors (Guo *et al.*, 2002; Liu *et al.*, 2006). Both represent different sedimentary environments. The Yaodian section analyzed in this paper consists of 80 m of horizontally bedded; mostly soft deposits that include a wide association of carbonate facies alternating with red and green clays.

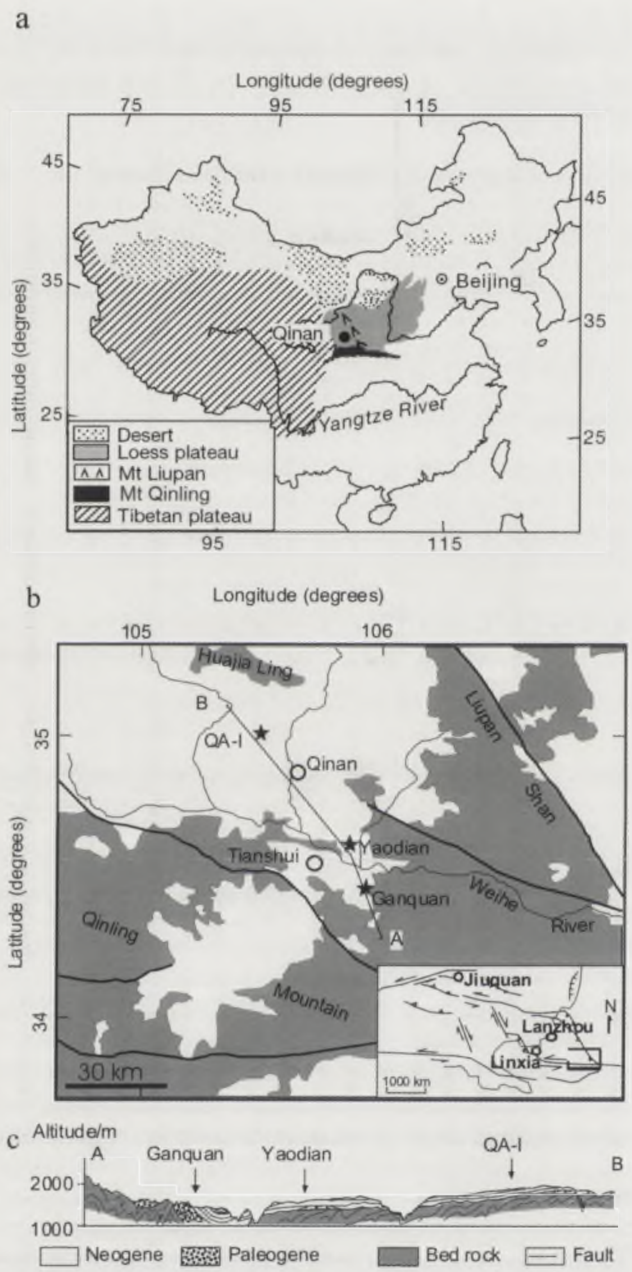

FIGURE 1. *Maps showing (a) situation of the Tianshui-Qinan Basin within China, (b) geologic background (insert) of the Qinan-Tianshui basin and locations of the sections and (c) cross section of the Tianshui-Qinan basin.*

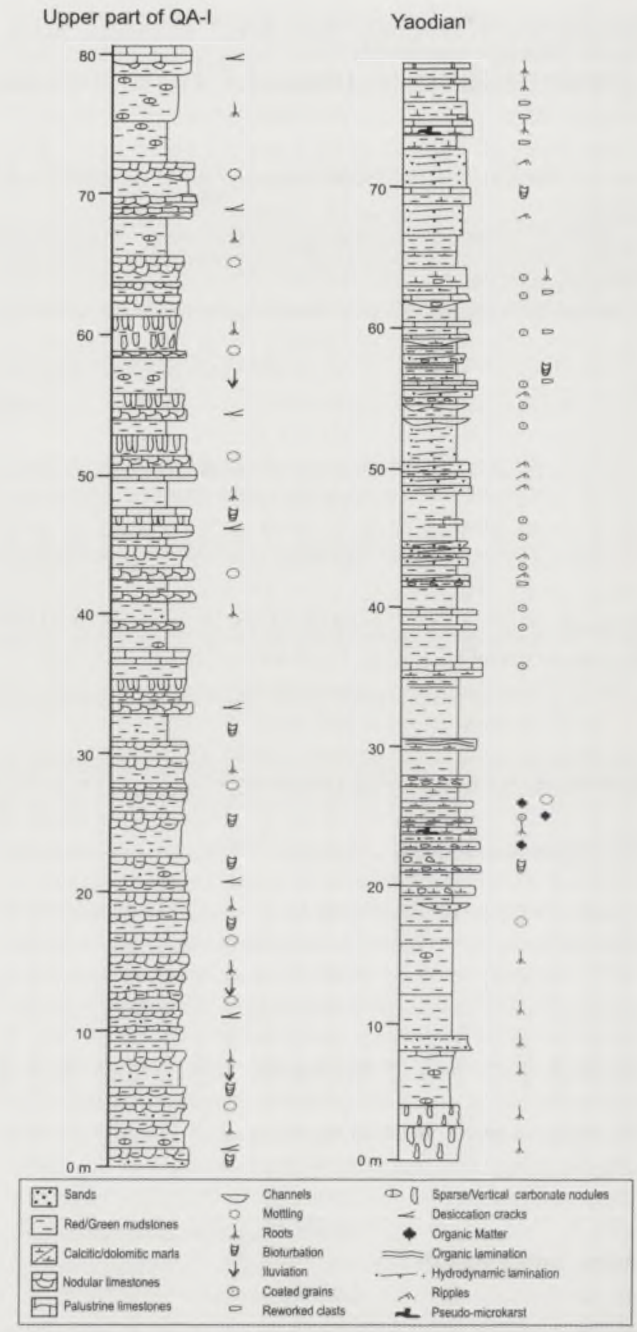

FIGURE 2. *Logs of Yaodian (mostly "Zebra Facies") and Upper part of QA-I sections.*

There are continuous changes in colour from red to green, that occur in a decimetre scale, but in cases in levels of a few centimetres thick. These facies are named "Zebra facies" and can be correlated all along the basin and represent very shallow lake environments. On the other side the upper part of QA-I section is mostly red in colour and apparently very homogeneous, although in detail many cycles show differences in the amount and texture of the carbonate that occur at the top of more clastic units (Fig. 2), indicate the neat stratification of these deposits, which mostly represent the transition from distal fan/mudflat areas to shallow lakes.

Shallow lake deposits

Shallow lake deposits include both carbonates and fine clastics deposits which are finely interbedded. The main lake facies recognized in both sections are the following:

1. Rippled sandstones/siltstones occur in beds of about 40 cm thick, they are grey to brown. They include mostly quartz grains and fragments of metamorphic rocks. Micas are also common as well as some micritic clasts (intraclasts). The sand grains show thin micritic coatings. A later sparry calcite cement is common. These deposits formed in shallow

and marginal areas of the lake, when clastics were sourced by the adjacent alluvial deposits.

2. Oolithic/peloidal packstones occur in centimetre beds, usually white. The ooliths are either embedded in micrite or loose. The ooliths are about 0.4 mm in diameter and show varied types of nuclei. Some nuclei are quartz grains but other are fragments of clay clasts with some silt grains (soft clasts). The number of coatings varies from one to a few. The coatings are regular and are formed either by calcite crystals or by micrite as a result of both micritization of these grains or just initial micritic coatings (Fig. 3A). In occasions oolithic limestones are interbedded within more peloidal limestones. The peloids are rounded and smaller (0.1 mm in diameter) and in occasions show a micritic coating.

3. Palustrine limestones are mostly micritic either calcitic or dolomitic. They show the typical palustrine features such as nodulization, mottling, desiccation cracks and pseudo-microkarst (Freytet and Plaziat, 1982; Alonso-Zarza, 2003) (Fig. 3B). In some cases, they include rounded and angular micritic grains formed as a result of grainification due to subaerial exposure. The filling of the cavities formed either by roots or desiccation including both types of micritic grains. Ostracods are rare and some quartz and mica grains are also present. Palustrine limestone represent the quiet margin of a ramp-like lake system.

4. Bioturbated marls are mostly green in colour and vary from massive to slightly laminated. They include some micritic carbonate nodules, millimeter in diameter, and cylindrical root tubes preserved in carbonate. They are interbedded with other deposits either clastics or carbonates. These marls represent the ponded areas of the distal fan areas close to the lake margins or the wet mudflat deposits of a wider lake environment; in either of the two cases they represent marsh areas with a wide vegetation cover and high groundwater table.

5. Intraclastic limestones/marls. These deposits are very commonly spread out all along the studied area. They consist of, usually angular, fragments of marls, mudstones or any type of limestones (Fig. 3C). The size of the fragments vary from sand to gravel. All the fragments are sourced from the nearby areas, either mudflat or shallow lake deposits. There are differences in the colour of the fragments, being red, white or green. They can be embedded either in a red or green matrix.

Distal fan/mudflat environments

Distal fan/mudflat deposits include also clastics and carbonates, that commonly alternate giving place to different types of sequences of about 1 m thick including from base to top: massive mudstones, pedogenic calcretes and groundwater calcretes that modify any of the previous deposits and can grade to palustrine limestones. These facies and sequences are mostly recognized in the QA-I section and in the lower part of Yaodian (Fig. 2) and include:

1. Red mudstones. They occur in beds from several cm to metres. They are from very fine sands to siltstones and commonly include micritic carbonate nodules. In other cases, specially at the base, they also include angular fragments of slightly lithified mudstones or limestones. These deposits represent the typical distal fan/dry mudflat areas, that in cases include reworked fragments of the previous slightly lithified deposits.

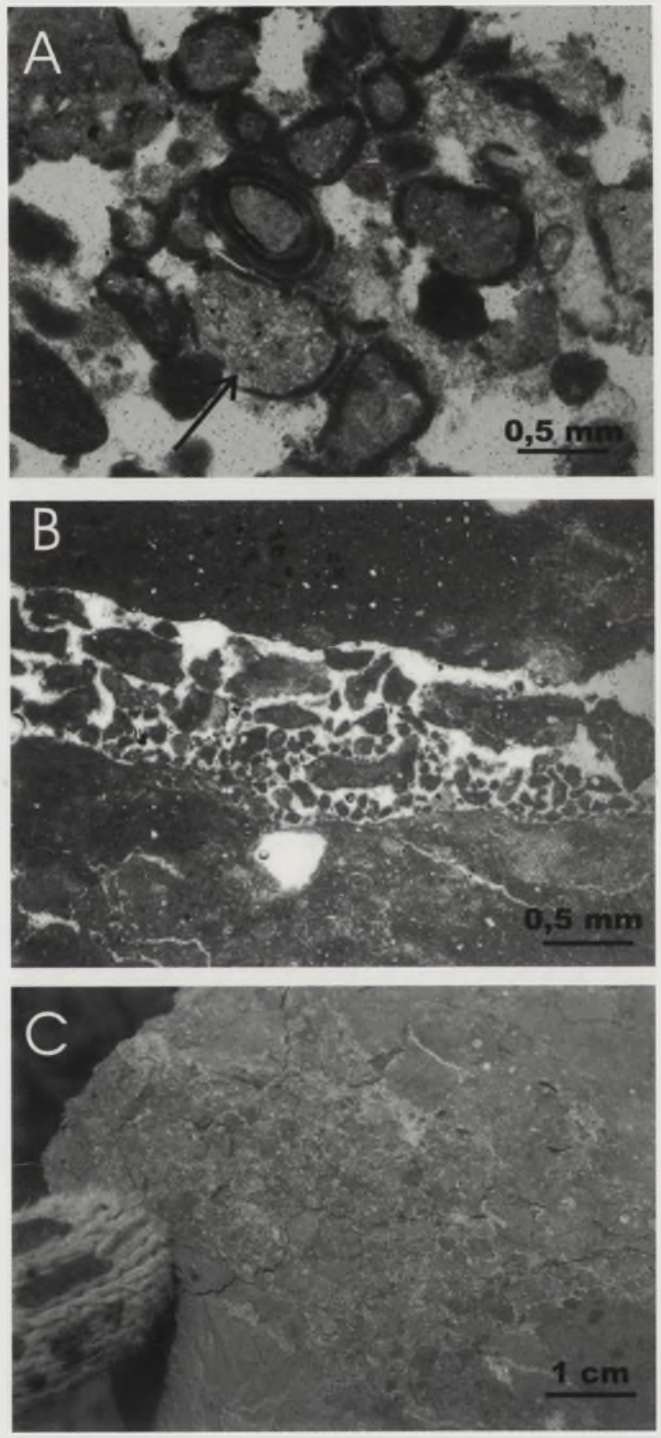

FIGURE 3. A, *Microphotograph of the oolithic/peloidal packstones (Yaodian), some of the nuclei are fragments of the mudflat deposits (arrowed); B, Palustrine limestone in Yaodian; the crack is filled by angular intraclasts; C, Hand sample of mudflat deposits containing fragments of the previously lithified mud (upper part of QA-I section).*

2. Pedogenic calcretes developed on the red clays and only reach stage III. Laminar calcretes have not been recog-

nized in these sections. The carbonates nodules are micritic and include some silt/sand grains. Mottling, desiccation cracks and root traces are common. The thickness of the profiles varies from 0.4 m to 2 m. These calcretes reveal the multiple events of subaerial exposure of these areas.

3. Groundwater calcretes developed on either of the two previously described deposits and show very gradual transitions at the base and sharper tops. They are not easy to define as they are formed by cementation and displacement of the previous deposits, so in cases they are very similar to the pedogenic calcretes. The main differences were the massive appearance and the dominance of non-biogenic features, as mostly show alpha fabrics (Wright and Tucker, 1991). The thickness is about 1 m and they show desiccation cracks, nodulization, cementation and replacement as the main features. It is not completely clear if at some points the groundwater could have reached the surface forming so palustrine deposits. Anyhow their presence indicates high groundwater tables.

4. Reworked calcrete deposits occur as channels and lenses of several decimetres in thickness and variable width from decimetres to hundred of metres. Their base is commonly erosive and include clasts of carbonates mm or cm in size that are very similar to the calcrete carbonate nodules. These deposits are clearly indicative of the reworking by flowing waters of the previous exposed mudflat/distal fan areas.

5. Sheet-floods and channels are not very common in the studied sections but occur locally and are widely recognized in other areas of the basin. Sheet-floods are laminated centimetre to decimetre thick silt to sandy deposits, usually cemented by carbonate. Channels are erosive on the red mudstones, the clasts are usually sand-sized and include quartz, fragments of metamorphic rocks and intraclasts.

INTERPRETATION AND DISCUSSION

The study carried on in this two sections provide new data to understand the paleogeography and evolution of the sedimentary environments of the Tianshui-Qinan Basin; however more data (dating, sedimentology, petrography) are still needed in order to have a complete overview of the basin. The overall sedimentological data point out to a closed basin, with a very flat topography in the inner parts, so that small variations in water and sediment supplies caused important changes in the sedimentation. This is specially clear in the lake deposits and also in the alternation of red mudstones and any type of calcretes. The arrangement of the sediments clearly point out to periodical desiccation and subaerial exposure of both of mudflats and shallow lakes. The desiccation lead to the disruption of the previous deposits that can be easily incorporated in the new sedimentary events. So, reworking was a very common process in the basin. The lake margins were varied, even being very flat (ramp-like), so lake margin deposits include some clastics, either sand or silts, and also ooliths. Low energy lake margins are represented by the marls, some of the intraclastic limestones and palustrine sediments.

The sedimentary environments and the composition of the sediments make very difficult to consider that all these deposits were formed by eolian processes. There are several reasons: the occurrence of water laid carbonates and also of diagenetic processes related to high groundwater tables (groundwater calcretes), the size and types of some components (intraclasts, calcrete nodules or even the sorting of some of the sandstone deposits), the fact that most of the deposits are mudstones and not siltstones or sandstones. However, it is possible that wind could have sourced some of the quartz grains and also favoured the higher energy of the lake margin at some points, but there is no way that all these sediments were deposited by wind.

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